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THE SMALL WIND TUNNEL OF THE DVL

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With the increasing demands on the performances and flight characteristics of airplanes, the testing of models in wind tunnels has proved to be a practical and indispensable aid, extensive use of which has been made in the aeronautic laboratories of all countries. The DVL (Deutsche Versuchsanstalt für Luftfahrt), which had previously had no conveniences for aerodynamic model tests, therefore considers it a special cause for congratulation that it was able, during the past year, to install a small wind tunnel.

I. GENERAL DESCRIPTION

In deciding on the general design and dimensions of the small wind tunnel, it was assumed that a large one would be subsequently added. Though the installation of a large wind tunnel had not been definitely decided at the time of beginning the construction of the small tunnel, the pressing need of it had been recognized by the authorities, so that its early inception could be anticipated.**

In view of this situation it seemed expedient to make the dimensions quite small, so as to reduce the cost of construction and maintenance as much as possible. A circular jet of 1.2 m (3.94 ft.) seemed sufficient for the immediate tasks. This is sufficient for testing many parts and also for certain tests with complete airplane models. In cases where the dimensions no longer suffice, an idea can always be obtained quickly and cheaply in the small tunnel regarding the probable phenomena, so as to relieve the large tunnel of this preliminary work.

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*"Der Kleine Windkanal der DVL." Z.F.M., October 28, 1933, pp. 559-562.

**In the meantime the construction of the large wind tunnel has been begun, with an optional elliptical jet section of 5 by 7 or 6 by 8 meters (16.4 by 23 or 19.7 by 26.2 feet).

In designing the small tunnel, it was planned to obtain as much experience as possible bearing on the design and construction of the large tunnel. The general arrangement (fig. 1) corresponds to the well-known Göttingen tunnel. The air is conducted in a closed circuit and flows freely through the experiment chamber, 2 m (6.56 ft.) long, between the entrance cone of 1.2 m (3.94 ft.) diameter and the exit cone.

In order to obtain useful Reynolds Numbers despite the small dimensions, it is endeavored to produce as high a velocity as possible. A 150-horsepower direct-current motor is used. It can deliver 230 hp. for a few minutes. In continuous running, the velocity in the free experiment chamber is about 65 m (213 ft.) per second, with a possible maximum of 80 m (262 ft.) per second, for a brief period.

II. AIR CONDUCTION

The tube, through which the air flows, is made of reinforced concrete in the Zeiss-Dywidag manner. The walls are 4 cm (1.57 in.) thick without plaster and paint. It is supported only at the four corners and at the base of the blower. The entrance cone and the mouth of the exit cone are cast from light metal. The cylindrical tube preceding the exit cone, which serves to quiet the air, and the exit cone are made of sheet iron.

The whole wind tunnel is housed in a simple brick building with a large and well-lighted experiment chamber. The 6-component balance is supported above the free jet by a welded iron framework. This balance, as likewise the adjustment and remote control of the motor, is served from a platform consisting of a transparent grill.

The guide vanes are welded from sheet iron and embedded in the wall of the tunnel. In order to be able to correct the deflection subsequently, strips of sheet iron, which can be easily bent, were welded to the trailing edges of the guide vanes at both corners adjacent to the entrance cone.

In operating the tunnel, an attempt was first made, by the suitable adjustment of these strips and of a few guide vanes, to obtain a uniform velocity distribution without a honeycomb straightener. It was found, however, that the time and energy required to produce good results, were entirely disproportionate to the cost of installing a straightener in so small a tunnel. A honeycomb straightener was therefore installed in place of the guide-vane grid. After its installation, the velocity showed a maximum variation of 0.3 percent at the individual points of the inner portion of the jet of 0.8 m (2.62 ft.) width and 0.5 m (1.64 ft.) height. In the same region the maximum variation in direction was 0.4°.

As the criterion for the turbulence of the jet, the critical Reynolds Number was determined at which a sphere 140 mm (5.51 in.) in diameter showed the well-known reduction in the drag coefficient. Before the installation of the straightener, the drag coefficient of $c_w = 0.3$ was reduced at $R = 260,000$; after the installation, at $R = 326,000$. Since this reduction is due to the frictional layer becoming turbulent and since it first occurs at a Reynolds Number which is high in comparison with measurements in other wind tunnels, it may be assumed that the turbulence of the jet is small, without doubt largely due to the relatively long quieting stretch.

III. BLOWER AND VELOCITY REGULATION

The blower is an aircraft propeller of 1.95 m (6.4 ft.) diameter mounted directly on the end of the motor shaft. The motor is mounted on two supports and is faired. In order to load the motor as heavily as possible without overheating, a special cooling fan is installed inside the motor fairing. This fan draws air through slots in the motor fairing and expels it through openings at the rear. This makes it possible to increase the power from 150 hp. to 230 hp. The speed of the motor is regulated by hand. The control table with all the switches is movable, so that it can be placed wherever it is most convenient, which is generally near the balance.

In order to maintain a given velocity during the whole test, slots are made in the tunnel walls back of the entrance cone where the highest pressure prevails. The escaping air is automatically regulated by shutters with the aid of an Askania tubular jet regulator, so that the velocity is kept constant throughout the experiment chamber. This control was first tested in a wind-tunnel model, which was exhibited in 1928 at the ILA (Internationale Luftfahrt-Ausstellung)* Oskar Schrenk recently proposed a regulator, based on the same principle, in which only the servo feature is omitted.** In its stead weights are introduced which maintain equilibrium with the pressure acting on the shutters from within and are varied according to the velocity desired. This simpler device has the disadvantage that, in large tunnels, large exit openings and correspondingly heavy weights are required. Moreover, the servo device, which can be bought quite cheaply, makes it possible to effect the control from any desired point. For these reasons the servo device was retained.

The velocity and pressure back of the entrance cone, which must be kept constant, can be controlled from the above-mentioned movable table. This method has proved very satisfactory. Since the regulator, in contrast with the devices for controlling the motor speed, has no mass (air mass, motor, blower) to be accelerated or retarded, it works very quickly. Serious disturbances are offset in 3 to 4 seconds, the maximum deviations from the adjusted velocity being about 0.3 percent.

A disadvantage of this method of regulating the velocity resides in the fact that a certain quantity of air must be constantly conducted in an adjacent flow. This air must be in such quantity that, in case of an increase in the resistance, or of any reduction in the motor output from closing the regulating shutters, the original velocity in the experiment chamber can be restored. The energy in this auxiliary air current is lost to the main jet. This loss, however, is not very great, unless great variations in the resistance of the model are offset by the air regulator alone without regulating the motor. An energy loss of about 5 percent must be accepted, in order to offset all the fluctuations occurring in an ordinary polar measurement. This scarcely affects the other advantages. With the shutters closed, the ratio of the energy consumed to the kinetic energy of the jet is

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*For a more detailed description, see M. Schilhansl, "Versuche an einem Windkanalmodell." Z.F.M., vol. 22, 1931, pp. 107-117 and 147-149; and D.V.L. Yearbook 1931, pp. 23-35.
**O. Schrenk: "Ein einfacher Druck- und Geschwindigkeitsregler für Versuchsgebläse und Windkanäle." Ing.-Arch., vol. I, 1929-1930, pp. 350-355.

$$\frac{N_{motor}}{\frac{\gamma}{g} F \frac{v^3}{2}} = 0.48.$$

IV. MEASURING THE VELOCITY

Since, in the present case, the slots for the regulation of the velocity are behind the entrance cone, the pressure measured at this point is no definite criterion for the velocity in the experiment chamber. The ratio of the velocity behind the entrance cone and in the experiment chamber differ according to what portion of the air escapes through the slots. If it is desired, in the usual way, to take the difference between the pressures behind the entrance cone and in the jet as the criterion for the velocity, the adjustment of the regulator must be taken into consideration. For this reason, the velocity is measured by determining the Bernoulli total pressure of the flow behind the entrance cone with the aid of pitot tubes. The difference between this pressure and the static pressure in the experiment chamber is then the criterion for the velocity. This pressure difference is shown by a Betz manometer, which is described in Ingenieur-Archiv 1931, and which has proved very satisfactory.

V. BALANCE AND MODEL SUSPENSION

The model is suspended on six wires, as can be seen in figures 2 to 4. Three of the wires form a pyramid with its apex at the point of suspension. Two other wires form a V, with its apex likewise at the point of suspension. There is also a vertical wire at the tail end of the fuselage. At the intersection point of the first three wires a fourth wire is attached, which only serves, however, to produce a preliminary tension, which is desirable for absorbing the lateral forces. For this purpose it is attached at the top to one arm of a lever, to the other arm of which weights can be applied. The model is attached to the wires by fittings, each containing a ball-and-socket joint, the center of which coincides with the point of intersection of the wires. The three wires descending from the attachment points carry plates immersed in a water tank set in the floor. By placing weights on these plates a preliminary tension can be produced and simultaneously a damping of any vibrations which may occur in the model. The angles between the intersecting wires are made as large as possible, so as to give the suspension the greatest possible rigidity.

The three pyramid-forming wires are attached at the top to a rigid disk, itself so supported that it can be shifted in three mutually perpendicular directions (vertical, parallel to the air stream, and crosswise to the latter). The component forces transmitted from the model to the intersection point of the wires are measured at the disk by suitably arranged balances. Similarly the two V-forming wires are attached to a carrier which can be shifted in two directions (vertical and parallel to the air stream), the corresponding components being measured by two balances. The last wire transmits the force directly to a balance. Measurement is thus made of all six of the component forces.

For measuring the moments, the points of attachment, as already mentioned, have the form of universal joints, the centers of which establish the axes for the aerodynamic moments. In order to keep the friction in these joints as small as possible, the descending tension wires are so connected with the suspension wires that the preliminary tension is transmitted directly to the suspension wires without stressing the joints. (For this reason, three tension wires are used at the three points of attachment of the suspension wires, although in principle, one wire should suffice, if the model were sufficiently rigid.)

In order to be able to vary the angle of attack, the suspension point of the wire attached to the tail end of the fuselage is secured to an adjustable lever, by which the rear suspension point can be raised or lowered. In changing the angle of attack, the model turns about the transverse axis determined by the joints of the other two suspension points.

The course angle is adjusted by rotating the whole suspension, including the balances, about a vertical axis. In doing this, the disk to which the three wires are attached, the beam to which the two V-forming wires are attached, and the lever for the last suspension wire, together with all the balances, are so controlled that they move in parallel circular paths.

In this manner of moving, each direction fixed by the arrangement, which is parallel to the air stream in the zero position, is also parallel to the air stream in every other position. All the components measured are therefore based on a system of axes which is fixed with respect to the direction of flow. Moreover, this manner of shifting makes it possible to use faired wires, since, in varying the course angle, they always retain the correct position with respect to the flow. Since this balance arrangement was intended to serve as a preliminary test for that of the large wind tunnel, for which a similar arrangement is provided, it was also made for the small tunnel in the manner described.

The forces are measured by hydraulic measuring gages. The forces act on a piston, which works on a liquid confined by a thin rubber diaphragm. The pressure produced in the liquid can be read in a vertical tube as representing the force exerted on the piston. In order to determine the shortest displacement distances, the ratio of the piston area to the cross section of the vertical tube must be as large as possible. In these balances, it is such that the maximum displacement, including the internal deformation of the rubber diaphragm, etc., is only 0.15 mm (0.006 in.). The vertical tubes are inclined according to the magnitude of the forces to be measured, in order to increase the sensitiveness for small forces. With the most sensitive adjustment, the displacement of the liquid in the vertical tube amounted to 400 mm/kg (7.14 in./lb.). A reading is accurate therefore to within about 1 g (0.035 oz.).

Alcohol was first used as the measuring liquid. It was found, however, that the great volumetric variations in alcohol with variations in the temperature necessitated a correction for the given temperature. For this reason water is now used as the measuring liquid, which has a temperature sensitiveness of only about one fifth that of alcohol. A little soap is added, in order to avoid the indication disturbances produced in pure water by the surface tension.

The whole 6-component balance is mounted on a car which can be moved laterally on an iron staging. In this way each of the suspension points can be brought to any desired position in the jet. Moreover, a model can be mounted outside the relatively narrow test section and then be moved into it. The reading of the balance, the adjustment of the angles of course and attack, as also the control of the blower and velocity, are all effected from a platform above the exit cone.

VI. SUMMARY

A wind tunnel with a jet diameter of 1.2 m (3.94 ft.) is described. In a series of experiments, both the general arrangement and the individual devices, such as the balance and the velocity control which differ somewhat from previous devices, have proved entirely satisfactory. The installation of the model and also the measurements, even when embracing all six components, can be accomplished very quickly. Numerous calibrations show that the balance yields accurate results. No disturbances were produced by the development of excessive stresses in making the model suspension sufficiently rigid. Subsequently the same measuring devices were introduced into the large wind tunnel, excepting for modifications necessitated by structural reasons due to the greater size. The small tunnel is now being used for model tests, which will be reported later.

The design and the solution of the problems arising during the construction were worked out by Dr. Schilhansl (aerodynamic portion, blower and velocity control), Dr. M. Kramer (6-component balance and operation of tunnel) and architect H. Brenner (structural form) in common with the writer.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

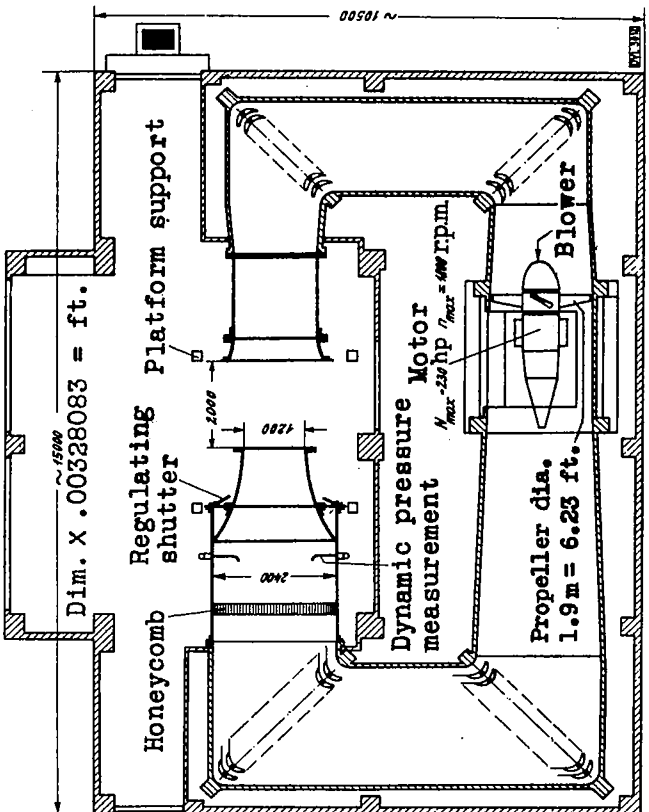

Figure 1.- Ground plan of small wind tunnel.

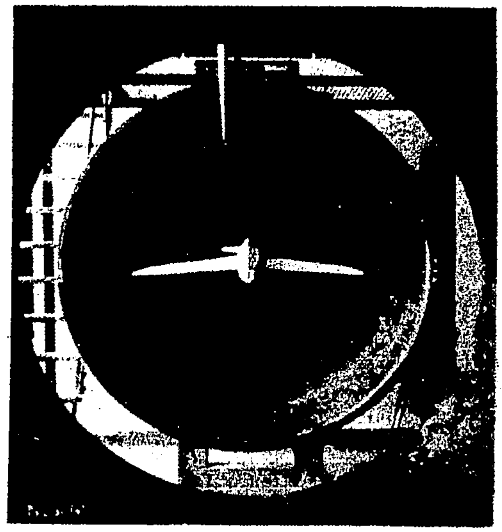

Figure 3.- Suspension of flying-boat model, looking through entrance cone toward exit cone.

Figure 2.- Experiment chamber with free jet and six-component balance.

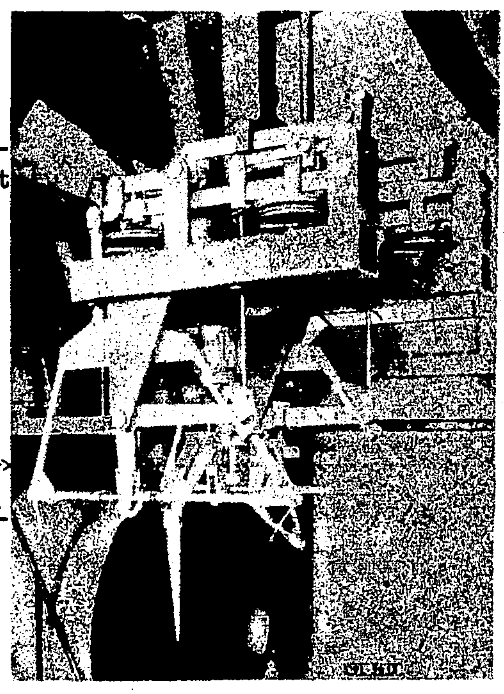

Figure 4.- Six-component balance.